MORPHOMETRIC, PHYSIOLOGICAL, HISTOLOGICAL,

AND BIOCHEMICAL CHANGES IN RAT FOOT EXTENSORS

IMMOBILIZED BY PLASTER

C.-P. Simard

Translation of   "Quelques modifications
morphométriques, physiologiques, histologiques
et biochimiques des tissus osseux et muscu-
laires de la patte de rat immobilisée par le
plâtre", La vie médicale au Canada Francais,
      Vol. 2, April, 1973, pp. 325 - 340

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D. C. 20546   MARCH 1974

CERTAIN CHARACTERISTICS OF THE FIELDS OF THE OUTGOING THERMAL RADIATION OF THE VENUS AND MARS ATMOSPHERE

A.M. Bunakova and K.Ya. Kondrat'yev

CERTAIN CHARACTERISTICS OF THE FIELDS OF THE
OUTGOING THERMAL RADIATION OF THE VENUS AND
MARS ATMOSPHERE

A. M. Bunakova and K. Ya. Kondrat'yev

.   The atmospheres of Venus and Mars have been extensively
studied in recent years [1]. Data from spectroscopic measurements
on the Earth and direct probes have provided a basis for studying
the thermal regime and the total situation of the atmospheres of
the planets [2]. Studies of the energy characteristics of the
planets are particularly important in this respect, including the
radiation balance (and its components — absorbed solar radiation
and outgoing radiation) which determines the basic characteristics
of the total circulation of the planetary atmospheres. Since
there are practically no data on the outgoing thermal radiation,
we calculated the spectral and angular distribution of the out-
going thermal radiation of Venus and Mars, taking the fact into
account that such data are of great interest for solving certain
applied problems. Naturally, the authenticity of the results
of these calculations is determined by the reliability of the
initial information regarding the composition and structure of
the. planetary atmospheres, and also a suitable model for the
radiation transfer. The model of the upper (above the cloud)
atmosphere of Venus, which was used for the calculations, was
borrowed from the literature, and is based on a combination of
existing spectroscopic data and the results of direct probes.

---

*   Numbers in the margin indicate pagination of original
    foreign text.

Based on data from direct measurements on the spacecraft Venera-5 and Venera-6, the chemical composition of the atmosphere of Venus is as follows [5]: 97% CO_2; a maximum of 0.4% O_2; < 2% N_2; ~1% H_2O (this pertains to the level $p = 0.6 \ amm$; $T = 300° K$).

According to indirect spectroscopic data [6], the atmosphere of Venus close to the upper cloud boundary may be best approximated by the following parameters: $p = 0.2 \ amm$, $T = 240-270° K$, $M_{CO_2} = 2 \cdot 10^{5} \ cm \cdot amm$, $M_{H_2O} = 2 \ cm \cdot amm$, $M_{CO} = 2-6 \ cm \cdot amm$, $M_{O_2} < 7 \cdot 10^{-1} \ cm \cdot amm$, $M_{HCl} = 2 \cdot 10^{-2} \ cm \cdot amm$, $M_{HF} = (2-6) \cdot 10^{-4} \ cm \cdot amm$, M — amount of gas per $1 \ cm \cdot amm$ for the mean free path of a photon during scattering.

The height of the upper boundary of the cloud layer of Venus is $60 \leqslant h_c \leqslant 70$ km (see, for example [7]). Processing the data on the occultation of Regulus by Venus [8] makes it possible to relate the maximum possible height of the upper boundary of the cloud layer to the scale of pressure and temperature. This height corresponds to $p_0 = 0.2 \ amm$, $T_0 = 230-250° K$. Only these data are important for the calculations, and the absolute height of the cloud layer does not play any role.

The temperature profiles used in our calculations are shown in Figure 1. The theoretical calculations of the temperature profile T (z) in the atmosphere of the clouds are carried out in the studies [9-11] and [9]. The influence of different factors upon the temperature profile above the clouds was studied, but the authors used an old model of the chemical composition of the atmosphere, which was invalidated by data from automatic inter-planetary stations. Nevertheless, the composition of the atmosphere and the cloud structure are the basic factors influencing the temperature. The study [10] calculated the diurnal and nighttime vertical distributions T (z) for different latitudes. It may be assumed that the profiles calculated for the atmosphere

2

above the clouds correspond to real conditions, since they were
obtained by using reliable data on the optical characteristics
of this portion of the atmosphere. They closely coincide with
the temperature data of Mariner-5 [12]. Definite information
regarding T (z) is given in [13].

Thus, all the information given on the temperature profiles
of the atmosphere above the clouds is obtained from theoretical
calculations which do not contradict existing experimental data.
Therefore, the problem of the reliability of these profiles is
still unsolved. As will be shown below, an analysis of the experi-
mental spectra of the outgoing thermal radiation may solve this
problem to a significant extent.

The intensity of the radiation of the cloud layer of Venus
is at a maximum between 3-20 µm (λ_{max} = 12.6 µm). The oscillatory-
rotational bands CO_2 and H_2O, which are most important when calcu-
lating the thermal radiation, are located here. Therefore, this
spectral range is of basic interest in these calculations.

We shall assume that the condition of local thermodynamic
equilibrium is satisfied in the planetary atmosphere, although
generally speaking, it may be disturbed at small pressures (for
the atmosphere of the Earth, for example, at p<0.8÷0.5 mB; for
Venus such estimates were not made).   /249

The calculations were performed by numerical integration
of the phenomenological transport equations

$$I(\lambda) = E(\lambda, T_0)P_0(\lambda, U_0) + \int_{P_0}^{P} E(\lambda, T)dP(\lambda, U), \qquad (1)$$

where P(λ, T) is the transmission function (U—absorbing mass),
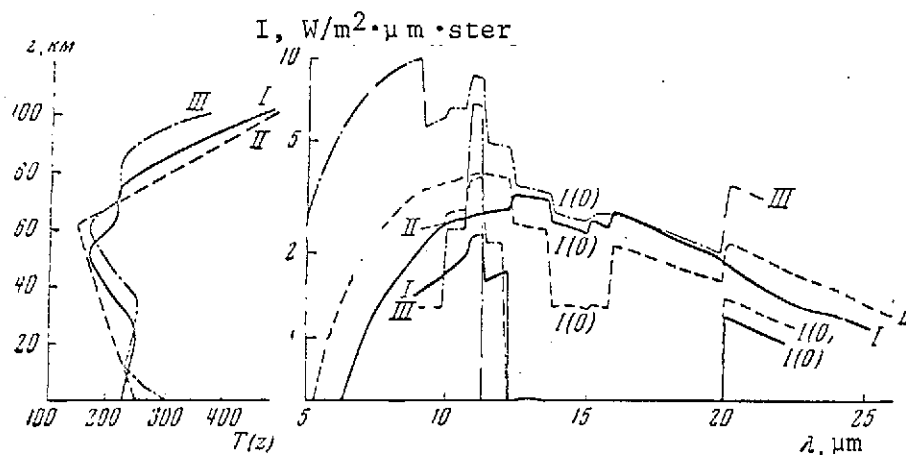E(λ, T) — radiation intensity of an absolutely black body.

Figure 1. Outgoing thermal radiation for different stratifications of the atmosphere (Venus) I(0) — radiation of a cloud transmitted by the atmosphere; z — height above the cloud layer

The upper boundary of a cloud with a temperature of T_0 and a pressure of p_0 represents the underlying surface for the atmosphere of Venus above the clouds. It is assumed that the cloud reflects like a black body.

Based on the probabilities of photon survival in the infrared region [14], even for the cloud layer of Venus aerosol scattering may be significant only in the transmittance window with a center at $\lambda \approx 11$ μm. Therefore, for the atmosphere of Venus above the clouds, the contribution of aerosol scattering to the transport of infrared radiation is insignificant and scattering is not taken into account.

A characteristic difference between the atmosphere of Venus and the atmosphere of the Earth is a much larger amount of CO_2 (the total content of U_t in a vertical column is $10^5 \, cm \cdot atm$). The differences in the conditions under which infrared radiation is propagated in the atmospheres of the Earth and the atmospheres of Venus above the clouds are due not only to the large absorbing masses (magnitudes of the optical path are required which are

4

practically unobtainable even in laboratory conditions), and
also to the fact that small pressures may occur ($p < 0.2$ atm)
as well as low temperatures ($T \approx 200-300° K$). All of this pro-
duces great difficulties when selecting the transmission
functions. There is particularly great uncertainty in existing
data regarding the transmittance of the atmosphere of Venus in
the wings of the bands and the windows between the bands of
absorption, because for these spectral regions, there are very
few experimental data for large U. Theoretical calculations of
$P(\lambda, U)$ are very cumbersome and are complicated by the fact that
for conditions existing in the upper atmosphere of Venus there are
no unequivocal data on the contour of the spectral lines.

Experiments may provide the most reliable information on
the transmission functions of a uniform medium. Since at the
present time there are no experimental data corresponding to a
real planetary atmosphere, it is necessary to resort to different
models and extrapolations. We have used the model proposed by
Hanel [9]. The approximation formula of the model is

$$P_\lambda(z, H) = \exp\left\{-\sum_i [k_\lambda^i w_e^i(z, H)]^{N_\lambda^i}\right\}, \quad w_e^i(z, H) = \int_z^H \rho_e^i(\zeta)\, ds(\zeta),$$

$$\rho_e^i(\zeta) = q_i \left[\frac{p(\zeta)}{1000}\right]^{(2N_\lambda^i + 1)} \left[\frac{173}{T(\zeta)}\right]^{1/2} e^{\gamma_\lambda^i \left(\frac{1}{250} - \frac{1}{T(\zeta)}\right)}, \tag{2}$$

$$ds(\zeta) = \frac{d\zeta}{\sqrt{1 - \frac{(R + H)^2}{(R + \zeta)^2 n^2(\zeta)}\sin^2\theta_H}}, \quad n(\zeta) = \left[1 + x\frac{p(\zeta)}{T(\zeta)}\right].$$

Here W_e is the effective mass of the absorbing matter; ρ - density;
q_i - concentration of the gas components; s - length of a ray in the
atmosphere; $k_\lambda i$- generalized absorption coefficient; N_λ^i takes
into account the degree of overlapping of the lines;

γ_i determines the temperature dependence of absorption; x - refraction parameter; n - refractive index.

The transmission functions obtained in [9], with a low and average spectral distribution, do not make it possible to describe the experimental spectrum in detail. Nevertheless, the spectral model proposed in [9] makes it possible to evaluate the most important phenomena and to reduce the computer time, which increases in proportion to the number of spectral points. When the radiation of the thin structure of the spectrum becomes important (for example, in the problem of the role of small admixtures in planetary atmospheres), it is necessary to use the transmission function with high resolution [15], which makes it possible to reproduce the thin structure of the absorption spectrum of CO_2.

It is known that in the case of significant absorption there is an increase in the contribution to the intensity of the second term in Equation (1), which is related to atmospheric radiation. Naturally, this contribution will be at a maximum at a wavelength where the contribution of the first term is decreased to the greatest extent. Therefore, it is advantageous to introduce the concept of an effective radiating layer located at the altitude z_e. With very strong absorption, the contribution to the outgoing radiation from the surface and the layers of the atmosphere near the surface is small (the radiation does not reach an altitude of H). The proportion of radiation of very high layers is small due to the small density of the radiating matter. The layers lying at a certain altitude $z_e (0 < z_e < H)$ make the basic contribution to the outgoing radiation. It is clear that z_e is determined from the condition that the derivative $\partial I(z, H)/\partial z|_{z_e}$ be at a maximum, where I(z, H) is the intensity of outgoing radiation formed by an atmospheric layer from z to H. Let us consider several possible cases.

6

a) Let us assume T (z) decreases monotonically with altitude, and the absorption increase (and altitude) leads to a decrease in the temperature of the radiating layer T_e. Therefore, a minimum in the spectral curve of I_λ will correspond to each region of intense absorption. The depth of the minimum is determined not only by the absorption intensity, but also by the gradient $\partial T / \partial z$.

b) A more unusual case is strong absorption when there is temperature inversion in the atmosphere. In this case, when the absorption increases, not only z_e but also T_e increase. As a result, instead of the usual minimums on the curves of I_λ (corresponding absorption regions) there will be radiation maxima. It must be noted that with a strong inversion, the brightness temperature determined in this range (approximately equalling the temperature of the effective radiating layer) may exceed the temperature of the underlying surface.

c) The most complex picture is observed when there is a non-monotonic change in temperature with altitude, when there are several temperature inversions.

Figure 1 gives the results of calculating the spectral behavior of the intensity of outgoing radiation corresponding to different stratifications. The intensity of the surface radiation is attenuated in certain cases by almost 100% (absorption band of 15 μm CO_2), and in these cases the outgoing radiation is completely produced by high atmospheric layers. Therefore, different temperature profiles lead to a great qualitative difference in the spectral curves of I_λ (Figure 1). The most typical case is observed for the profile II which has practically no inversion (inversion at the altitude z = 60 km may be disregarded because the density is very low there).

As the calculations show, outside of the absorption bands the contribution to the outgoing radiation from atmospheric layers at different altitudes decreases monotonically with altitude, and in the absorption band the basic radiation comes from the high atmospheric layers $(z_c = 24 \, \text{км})$.

The spectral dependence of I_λ for the profiles I and III is much more complex. For the profiles I, for example, it is difficult to speak of a minimum corresponding to a strong absorption band of CO_2 15 µm, but there is a radiation maximum in the region $\lambda = 13$ µm which is not related to the maximum or the minimum of the transmission function. The structure of the spectrum obtained for the profile III is even more complex. As was indicated above, this is due to the complex behavior of T (z) with several inversions.

For purposes of comparison, Figure 1 gives those curves characterizing the contribution of the radiation of the cloud (I(0) – radiation of a cloud transmitted by the atmosphere). It can be seen that the outgoing radiation occurs primarily in the atmosphere above the clouds: 1) Practically in the entire wavelength range, the contribution of the atmosphere above the clouds to the outgoing radiation is either of the same order of magnitude, or somewhat greater than the contribution of the cloud layer, (2) The basic characteristics in the spectral behavior of outgoing radiation are related to the atmosphere above the clouds. One exception is the narrow transmittance window in the region $\lambda = 11$ µm. However, it can be seen that only in the case of the profile III is there a small maximum connected with the cloud radiation maximum. For the profiles I and II, such a correlation is not observed: it is completely hidden by the spectral behavior of the radiation of the atmosphere above the clouds.
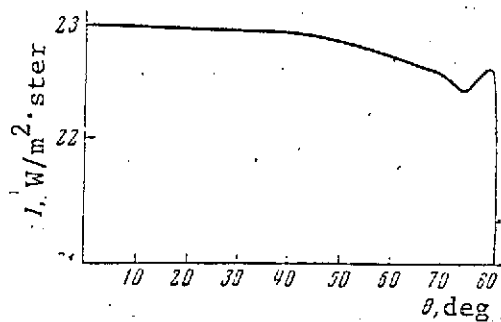
8

Figure 2. Total intensity of radiation for stratification III in the range 10-20 μm (Venus)

An example of the angular dependence of the total radiation intensity in the range 10-20 μm for the profile III is given in Figure 2. It is interesting to note the partial "lightening" at the edge of the disk, which is probably related to a temperature inversion: at large angles the radiation comes from the upper, more intensely heated layers of the atmosphere.

It is interesting to compare the results obtained for the upper atmosphere of Venus with those observed in the case of the atmosphere of Mars (Figure 3); temperature profiles were taken from [15]. The analogy between the structures of the upper atmosphere of Venus and the atmosphere of Mars makes it possible to carry out calculations for both atmospheres at the same time. The chemical composition of the atmosphere of Mars barely differs from the atmosphere of Venus (CO_2 - as before, the basic absorbing component). The temperature of the underlying surface lies in the same region; however, the density close to the surface of Mars is two orders of magnitude less than the density of the atmosphere of Venus at the upper boundary of the cloud layer. Therefore, typical properties of a strongly absorbing atmosphere are not so sharply expressed in the case of Mars. As may be seen from Figure 3, only for the profile III is there an emission behavior of $I(\lambda)$, which is typical for strongly absorbing atmospheres with
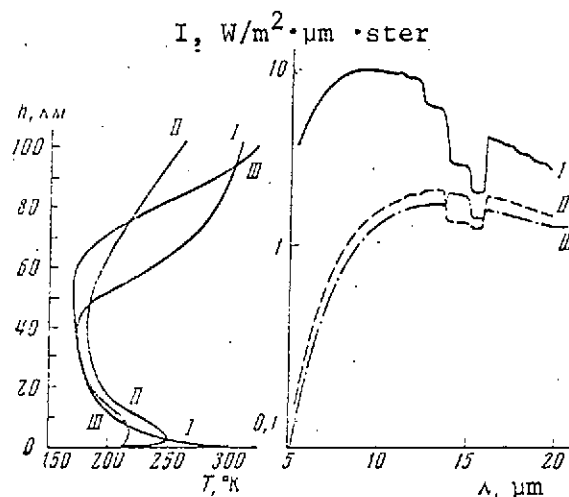
Figure 3. Outgoing thermal radiation of the atmosphere of Mars for different stratifications

a temperature inversion (maximum on the curve of I_λ at $\lambda - 14.5$ μm).*

For several spectral intervals, calculations were performed for the well known transmission function of Moskalenko and Golubitskiy [15]. A comparison of the results of the calculations, which was performed for different spectral intervals with the transmission functions of different authors, showed that on the average the results differed from each other by 30%.

The experimental data existing at the present time on the outgoing thermal radiation of the planets [13, 18] encompass a very small spectral interval 8-12 μm. They agree fairly well with the results of our calculations.

Based on the results obtained, we may conclude that the upper atmosphere of Venus and even the atmosphere of Mars are

---

*   The spectra of outgoing thermal radiation, which were obtained on Mariner-9 for the Southern Polar Cap and which were published after this article was written [17], also have an emission character. Based on this character of the radiation spectrum, a conclusion may be reached regarding the temperature inversion in the region near the poles for $z \leqslant 10$ км . This confirms our conclusion regarding the possible refinement of the temperature profiles with respect to the spectra of outgoing thermal radiation.

10

poorly transmittant for infrared radiation, i.e., for many spectral regions outgoing radiation is formed in the upper layers of the atmosphere. Therefore, outgoing radiation is very "sensitive" to the selection of a certain stratification of the upper layers of the atmosphere. This indicates that experimental data on the spectral distribution and angular dependence of infrared radiation make it possible to fairly reliably reproduce the temperature profiles for the atmosphere of Mars and Venus [19].

In conclusion, we would like to perform certain calculations connected with the integral flux of the outgoing radiation of Venus Φ

$$\Phi = 2 \int_0^\pi d\varphi \int_0^{\theta\text{max}} I(\theta, \varphi) \cos \theta \sin \theta \, d\theta.$$

The table gives the values of the fluxes of outgoing radiation calculated for different stratifications of the atmosphere and with different transmission functions (Φ is the flux of outgoing radiation obtained by using the transmission functions of [9], Φ' - flux of outgoing radiation calculated with the transmission function of [15]), Φ'' - flux produced only by the radiation of a cloud transmitted by the atmosphere (in this case the second term in Equation (1) is not taken into account - the eigen thermal radiation of the atmosphere). The effective temperatures T and T' corresponding to Φ and Φ' are calculated according to the formula

$$\Phi = \sigma T_e^4.$$

A comparison of Φ with Φ' and Φ'' and also T and T' with T (0)) confirms the important role of the atmosphere.

11

Stratifi-cation	Φ, W1/m^2	Φ', W1/m^2	Φ'', W1/m^2	T_e, °K	T_e', °K
I	·150,01	119,72	160,11	226,7	213,8
II	169,84	135,61	222,64	234,1	220,9
III	312,82	240,33	461,70	272,4	256,1

For further calculations connected with the energy character-
istics of the planet, precise information is first required on
the optical properties of a cloud. In addition, it is necessary
to examine the upper atmosphere of Venus in interaction with
the layer above the clouds. In addition to the greenhouse effect,
refraction is important, since beginning with a certain θ, the
outgoing radiation from the surface of the planet returns to it
(as was shown in [20], refraction does not have a great influence
on the radiation transport and the atmosphere of Venus above the
clouds).

REFERENCES

1.   Issledovaniya atmosfer Marsa i Venery (Studies of the
         Atmospheres of Mars and Venus). Edited by K. Ya. Kondrat-
         'yev). Gidrometeoizdat, 1970.

2.   Zilitinkevich, S. S., A. S. Monin, V. G. Turikov and D. B.
         Chalikov. Numerical Modeling of Circulation of the Venus
         Atmosphere. Doklady AN SSSR, Vol. 197, No. 6, 1971.

3.   Gavrilin, B. L., and A. S. Monin. Calculation of Climatic
         Correlations based on Numerical Atmospheric Models.
         Izvestiya AN SSSR, Fizika atmosfery i okeana, Vol. 6,
         No. 7, 1970.

4.   Sasamori, T. A Numerical Study of the Atmospheric
         Circulation of Venus. J. Atmos. Sci., Vol. 28, No. 6,
         1971.

5.   Marov, M. Ya. Model of the Atmosphere of Venus. Doklady
         AN SSSR, Vol. 196, No. 1, 1971.

6.   Belton, M. J. S. Theory of the Curve of Growth and Phase
         Effects in a Cloudy Atmosphere. Applications to Venus.
         J. Atmos. Sci., Vol. 25, No. 4, 1968.

12

7. Hunt, G. E. and R. A. J. Schorn. Height Variations of Venusian Clouds. Nature, Phys. Sci., Vol. 233, No. 37, 1971.

8. Vaucouleurs, G., and D. H. Menzel. Results of the Occultation of Regulus by Venus. July, 1959, Nature, Vol. 188, No. 28, 1960.

9. Bartko, E., and R. Hanel. Non-gray Equilibrium Temperature Distributions above the Clouds of Venus. Astrophys. J., Vol. 151, No. 1, 1968.

10. P. Fabian, T. Sasamori and A. Kasahara. Temperature Calculations of the Venus Atmosphere up to 80 km Height. Paper presented to the Symposium on Radiation. Bergen, 1968.

11. McElroy, M. B. The Upper Atmosphere of Venus. J. Geophys. Res., Vol. 73, No. 5, 1968.

12. Rasool, S. L. and R. W. Stewart. Results and Interpretation of the S-band Occultation Experiments on Mars and Venus. J. Atmos. Sci., Vol. 28, No. 6, 1971.

13. Hanel, R., M. Forman, G. Stamback and T. Meilleur. Preliminary Results of Venus Observations between 8 and 13 Microns. J. Atmos. Sci., Vol. 25, No. 4, 1968.

14. Samuelson, R. E. The Particulate Medium in the Atmosphere of Venus. J. Atmos. Sci., Vol. 25, No. 4, 1968.

15. Golubitskiy, B. M. and N. I. Moskalenko. Functions of Spectral Transmission in the Vapor Bands of H_2O and CO_2. Izvestiya AN SSSR, Fizika atmosfery i okeana, Vol. 4, No. 3, 1968.

16. Tatom, F. B., P. B. Desphande, F. T. Hung and O. H. Vaughan. Prediction of the Martian Thermal Environment. AIAA Paper, No. 749, 1968.

17. Hanel, R. A., B. J. Conrath, W. A. Hovis, V. G. Kunde, P. D. Lowman, J. C. Pearl, C. Prabhakara, J. C. Schlachman, and G. V. Levin. Infrared Spectroscopy Experiment on the Mariner-9 Mission. Preliminary Results. Science, Vol. 175, No. 4019, 1972.

18. Gillet, F. C., F. J. Low and W. A. Stein. Absolute Spectrum of Venus from 2.8 to 14 microns. J. Atmos. Sci., Vol. 25, No. 4, 1968.

19. Timofeyev, Yu. M., and T. A. Dvorovik. Possibilities of Thermal Probes of the Atmosphere of Mars. Kosmicheskiye issledovaniya, Vol. 10, No. 1, 1972.

20. Kondrat'yev, K. Ya., A. M. Bunakova and M. V. Anolik. Characteristics of Thermal Radiation of the Atmospheres of Mars and Venus. Collection: Perenos izlucheniya v atmosfere (Radiation Transport in the Atmosphere). Izdatel'stvo LGU, 1972.

1. Report No. NASA TT F-14,764	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle CERTAIN CHARACTERISTICS OF THE FIELDS OF THE OUTGOING THERMAL RADIATION OF THE VENUS AND MARS ATMOSPHERE		5. Report Date March, 1974
		6. Performing Organization Code
7. Author(s) A. M. Bunakova and K. Ya. Kondrat'yev		8. Performing Organization Report No.
		10. Work Unit No.
9. Performing Organization Name and Address SCITRAN, P. O. Box 5456 Santa Barbara, California, 93108		11. Contract or Grant No. NASw 2483
		13. Type of Report and Period Covered Translation
12. Sponsoring Agency Name and Address NASA Washington, DC 20546		14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract   A study of spectral and angular variations of the outgoing thermal radiation for the atmosphere of Mars and the upper (above-cloud) atmosphere of Venus has been performed using the numerical method for the solution of the transfer equation. Calculations of the intensity of thermal radiation $I_\lambda(\theta, H)$ are made for the spherical pure CO_2 atmosphere. The values for $I\lambda(\theta,H)$ are calculated in a spectral range of $\lambda = 3\ (0.1)\ 50$ μm for zenith angles $\theta = 0\ (0.5)\ 85°$ at a height of the observational point $H = 100$ km. Comparison is made of outgoing radiation integral fluxes of Venus as calculated for various models of its atmosphere. It is shown that the character of the spectral and angular variation of radiation essentially depends on the choice of the upper atmospheric stratification.

17. Key Words (Selected by Author(s))	18. Distribution Statement Unclassified - Unlimited

19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 17	22. Price 4.00